is reported as occurring along the Pelly and Dease Rivers (Dawson[1] and Hayes;[2]) to the west, between the northern base of the St. Elias Mountains on the Yukon River (Hayes[3]); along the Upper Tanana River (Allen[4] and Brooks[5]), which is correlated by Spurr with the granite along the Pelly River; along Fortymile Creek, a tributary of the Yukon near the Canadian-Alaskan boundary (Spurr[6]); forming the core of the Kaiyuh Mountains (described by Dall,[7] referred to Archean by Spurr[8]); possibly forming the core of the Alaska Peninsula and the Aleutian Islands (noted by Dall[9] and Purington,[10] referred to Archean by Spurr[11]).

C. K. LEITH.

On Rival Theories of Cosmogony. By the REV. O. FISHER. *American Journal of Science*, June 1901, Pp. 414–422.

In this article the author has brought the current gaseo-molten hypothesis of the origin of the earth into comparison with the hypothesis of gradual accretion without a molten state recently advanced by Chamberlin, and has endeavored to test the tenability of the newer hypothesis by subjecting some of its fundamental postulates to mathematical and physical inquiries. The author disclaims holding a brief for either hypothesis and well sustains his claim to an impartial attitude.

[1] GEORGE M. DAWSON: Geological Natural History Survey of Canada, Vol. III, Pt. I, 1887–8, p. 34B.

[2] C. WILLARD HAYES: Geographic Magazine, Vol. IV, 1892, p. 139.

[3] Loc. cit., p. 139.

[4] LIEUTENANT H. D. ALLEN: Expedition to the Copper, Tanana, and Koyukuk Rivers, Senate Documents, Washington, 1897, p. 159.

[5] A. H. BROOKS: Twentieth Ann. Rept. U. S. Geol. Surv., Pt. VII, 1900, pp. 460–465.

[6] J. E. SPURR: Eighteenth Ann. Rept. U. S. Geol. Surv., Pt. III, 1898, pp. 134–140.

[7] W. H. DALL: Seventeenth Ann. Rept. U. S. Geol. Surv., Pt. I, 1896, pp. 862, 863.

[8] J. E. SPURR: Twentieth Ann. Rept. U. S. Geol. Surv. Pt. VII, 1900, pp. 235 and 241.

[9] W. H. DALL: Seventeenth Ann. Rept. U. S. Geol. Surv., Pt. I, 1896, p. 135.

[10] C. W. PURINGTON: Manuscript map referred to by Spurr.

[11] J. E. SPURR: Twentieth Ann. Rept. U. S. Geol. Surv. Pt. VII, 1900, pp. 233–235.

He cites at the outset a difficulty, "perhaps more apparent than real," encountered by the newer hypothesis in the sporadic arrangement of the meteoric material which, if like known meteorites, would differ from the existing surface rocks. This difficulty, however, loses much, if not all, of its force when the effects of volcanic action are considered. The hypothesis assumes that the interior heat which arises from compression gives rise to the melting of certain constituents of the rock mass, and that these, previous to eruption, undergo magmatic differentiation into the well-known igneous rocks and probably into others which are but rarely ejected because of their high specific gravity, as the iron-bearing basalt of Disco Island, Greenland, and other extremely basic rocks of the ferro-magnesian type. Volcanic action is assumed to have begun effectively before the growing earth reached the size of the moon and all accretions subsequently made would be more or less invaded and overflown by igneous intrusions and extrusions of differentiated lava. In the closing stages of the earth's growth, the infall of meteoric matter declined gradually to an inappreciable amount, while the volcanic action is thought to have continued with relative vigor for a notable period after the essential cessation of growth, and to have perpetuated itself in less activity down to the present time. If the moon may be taken as an illustration of the prevalence and effectiveness of surface vulcanism in a body one eightieth of the earth's mass, it does not seem violent to suppose that the original meteoric matter of the earth would be deeply buried under surface lava flows and tuffs in the closing stages of its growth. Recent studies in the Lake Superior region, in Scandinavia, and in Lapland seem to concur in showing that the oldest known rocks consist of such lava flows and pyroclastic layers associated with some small amounts of ordinary clastic material, all mashed into schistosity. Into these schists, the great granitic series were intruded. Under the newer hypothesis these intrusions are to be regarded as merely a continuation of the earlier active vulcanism which was then more largely basic, but which had now, in the progress of magmatic differentiation, attained a dominant acidic character, perhaps as the partial complement of the earlier basic flows of the schist series or of the later basic flows of the Algonkian. The "fundamental gneiss" does not, therefore, appear, in the light of these recent studies, to be *fundamental*, nor does the "basement complex" appear to be *basal*. These recent investigations seem to bring the Archean series into almost

ideal conformity with the accretion hypothesis, if under that hypothesis the process of accretion is conceived as dying away gradually by a transition into a stage of dominant vulcanism, which in turn gradually passes into the present phase of dominant aqueous activity. On the other hand, progressive investigation seems more than ever to give negative results in the line of the discovery of "the original crust" of the hypothetical molten stage, and the survival of the older hypothesis will perhaps require the recognition of a dominant eruptive stage similar to that postulated by the newer hypothesis, to which all or most of the Archean rocks are to be referred. In the light of these late Archean investigations, the difficulties of the old hypothesis seem at least as great as those of the new, for the old hypothesis must account for the non-appearance or scant appearance of "the original crust," while the new must account for the non-appearance or scant appearance of the supposed highly basic, magnesian, iron-bearing meteoric matter. The new hypothesis has the advantage of having theoretically postulated in advance what field studies are now bringing into recognition in spite of prepossessions inherited from the older view.

Passing the problem of superficial constitution as not necessarily serious, Fisher justly regards the increase of internal density and high internal temperature as incontestable facts of radical importance, and inquires how these facts may be accounted for on the meteoric theory. He assumes the average density of the meteoric matter to be nearly that of average surface rock, 2.75, and adds that "if this is too low, the arguments based upon it will not be affected in any great degree." Fisher feels tolerably certain that the law of internal density is fairly represented by Laplace's law, which is that "the increase of the square of the density varies as the increase of the pressure." In the case of a slow growth by solid accretion, the internal density must be mainly referred to compression. If, however, the specific gravity of the original meteoric material be taken at some figure between 3.5 and 4, as derived from known meteorites (Farrington's figure in 3.69), the amount of compression is appreciably less than on the assumption of 2.75 made in the computations. Fisher finds that at a depth of 400 miles, where by Laplace's law the density should be 3.88 the compressibility would be 1.4021×10^{-6}. "This may be looked upon as a small compressibility, seeing that the compressibility of water similarly measured is 4.78×10^{-5} or nearly forty times as great." The linear

dimensions would be reduced about one tenth. "At the center the compressibility similarly measured would be very small, viz., 2.5×10^{-7}, while the condensation would be large, viz., 0.744."

In the absence of direct measurements on the compressibility of rocks, the author computes its value from the values of Young's modulus and the modulus of rigidity which have been obtained in some instances, and compares the result with the theoretical compressibility of surface rocks deduced from Laplace's law. Respecting the results, he remarks that "it is certainly not a little remarkable how closely this value ranges with those found by experiment. It is of the same order of magnitude but rather smaller than the average." He adds:

We find here a somewhat strong presumption in favor of the view that the earth consists throughout of matter not very dissimilar from what we know at the surface, and that the internal densities are due rather to condensation than to the presence of heavier substances such as metals. But it is not a proof of this.

Respecting the alternative view that the greater density toward the center is due to heavy metals, Fisher says:

We may probably dismiss the supposition that these all fell in first, and only regard them as segregated from a uniform mass of some kind, and having gravitated towards the center. This implies a condition of liquidity. If the materials were solid this separation could not have occurred. Now the only force that we know of that could cause the denser materials to move by a kind of convection towards the center is gravity; and in a solid gravity would not have that effect. Moreover, it must not be forgotten that gravity continually diminishes as we go deeper into the earth, and that at the center bodies have actually no weight. It is greatest at the surface, and if not competent to segregate downwards the heavy particles of a rock at the surface, which we know it is not, still less could it have that effect near the earth's center.

Neither can we attribute this segregation to pressure; for pressures act equally upon the surface of heavy or light materials. If we had a layer of mixed shot and sand, no steady pressure laid upon it would force the shot to the bottom and bring the sand to the top.

It seems, therefore, that the view that the denser materials in the interior consist of heavy metals necessitates a condition of liquidity of the whole, which accords more readily with the nebular than with the meteoric theory of its origin. For we may imagine that in a nebular mass cooling from the exterior, the first change from a nebulous or gaseous state would be the formation of a rain of condensed particles falling downwards, which would continue until the whole mass became liquid, and thus the heavier elements would begin to

collect towards the center. In this case the highest possible interior temperature would be that at which the gaseous first assumed the liquid condition under the pressure at the depth.

Paradoxical as it appears, it is therefore possible that the temperature in the interior may have been rendered higher by a conglomeration of cold solid meteorites than by the cooling of a nebula.

We have no means of judging whether the meteorites would come in rapidly or slowly, but in either case if we take no account of the heat arising from impact, the amount produced by condensation would be the same; the only difference in the two cases being that it would be generated in a less or greater time. In the meanwhile a covering of a badly conducting material would concurrently accumulate, preventing the rapid escape of this heat, and at the same time increasing the pressure, the compression, and the heat.

To form an idea of the temperature which would be produced by the condensation of matter of surface density to the density now existing at any given depth within the earth, not taking into account its diffusion by conduction or otherwise, we require to know the work which has been expended upon it. Now we can estimate this in the following manner. Conceive the earth to have been built up of meteorites falling in, so that shell after shell accumulated until the globe attained its present size. Then, fixing the attention upon a particular unit volume, say a cubic foot, of the substance, and omitting atmospheric pressure, it would successively be subject to every degree of pressure from zero, when the shell of which it formed a part was not covered up, until the present pressure was reached, when it was buried to the depth at which it now lies. If then we know the relation between the pressure and the compression at every depth at the present moment, it will give us the relation between the pressure and the compression which that particular volume has obeyed during the course of ages; that is to say, we can judge how much compression any given pressure would have produced in the substance under the conditions involved.

Laplace's law of density being based upon the assumption that the increase of pressure within the earth is proportional to the increase of the square of the density, in terms of a pressure of one pound upon the square foot, this leads to the result, that the pressure at the depth where the density is p is equal to $5.9\times 10^7\ (p^2-s^2)$ [where s=density of surface rock and p= density of rock at the depth under consideration].

If we accept Laplace's law, this expresses a fact, whether the increase of density is due to condensation by pressure or to increased density in the intrinsic nature of the matter. But if we assume that the increase of density is caused solely by the pressure, then the above relation gives the amount of pressure which would reduce matter of density s to matter of density p under circumstances existing within the earth. It will therefore remain true if the

matter changes its state from solid to liquid, and from liquid to gas. If, for instance, we wished to apply a pressure which would reduce surface rock to the density 3, it ought to be $5.9 \times 10^7\ (9-2.75^2) = 8.481 \times 10^7$ pounds per square foot, supposing no heat be allowed to escape. If the experiment could be made, it would afford a test of the truth or otherwise of the present hypothesis.

When we know the relation between the pressure and the condensation which it would produce, it is feasible to estimate the heat which would be generated, and also the temperature, provided we assume the specific heat of the substance, which for surface rock has been determined. For instance, at the depth of 0.1 of the radius, or about 400 miles deep, where the density would be 3.88, the temperature produced by condensation would be 1.2608×10^5 Fahr., or 7.0044×10^4 Cent. [70,044°], while at the center the figures would reach 2.7756×10^6 Fahr., or 1.0242×10^6 Cent. [1,024,200°]. It seems at any rate that the meteoric theory would not fall short of accounting for temperatures as high as might be desired. It must at the same time be remembered that much of this heat would not be called into existence until the substance into which it was, as it were, being squeezed, had already been deeply buried under a badly conducting covering, so that the escape of heat would not take place as fast as it was generated, as would probably be the case with heat generated at the suface by impacts. Thus the hypothesis that the present high internal temperatures are due to compression seems quite admissible.

We may compare the above named temperatures with some that are known. Acheson, for instance, obtains 6500° Fahr. in his Carborundum electric furnace, and 3300° Fahr. has been obtained by the oxyhydrogen flame. These temperatures are contemptible compared with those mentioned above. The Hon. Clarence King, prolonging Dr. Barus' line for the melting point of diabase (which is 1170° C. at the earth's surface) to the earth's center, gives the temperature 76000° Cent., which is of the same order of magnitude as condensation would produce at only 400 miles depth.

Fisher considers the bearing of the temperature of lava as determined by Bartoli at Etna (1060°C. or 1932° F.) on the question, and finds that the theoretical depth at which this lava temperature would be produced by condensation would be about forty-three miles. The same temperature would be reached at the accepted gradient of 1° F. for sixty feet in about twenty-two miles.

It seems then that the hypothesis, that the internal densities are due to the condensation of matter of surface density, will not account for a temperature gradient originally as high as at present. [The computed gradient corresponds pretty nearly with the low gradient found at the Calumet and Hecla

mine.] Nevertheless the above observations upon the temperature of lava, and the comparatively small depth, forty miles, at which condensation of rock would be capable of producing it, together with the small amount of condensation necessary, viz., 0.041, render it quite probable that fusion may have ensued in the deep interior without the necessity of a greater amount of condensation than such materials might be supposed capable of under the enormous pressure to which they would be subjected, even allowing for the increase of the melting point under pressure. . . . . It will be noticed that a compression less than would be requisite of itself to produce the necessary density would be sufficient to produce the requisite temperature for fusion. But while any stratum was cooling by the conduction upwards of its own heat of compression, it would be receiving heat from regions below, where, so long as condensation was going on, the materials would grow hotter and hotter. It seems therefore possible that the upper layers, forming what we call the crust of the earth, may have received sufficient heat supplied from below to render the temperature gradient at the present time higher than it was originally, and that even those Archean rocks, which are by many thought to have been once melted, do not necessarily prove that the earth was not built of cold meteorites.

The presence of water upon the earth has to be accounted for, and the meteoric theory does not easily lend itself for this purpose. Not only is water present in the ocean and in the atmosphere, but also in a state of solution in the interior, as is testified by the enormous amount of steam emitted by volcanoes, and by cooling lava. It does not seem possible that molten rock can imbibe water from without, because it would be driven away instead of attracted, since the superficial tension of a substance diminishes as the temperature rises.

The problem of accounting for the vast quantities of steam emitted by lavas is shared by both theories. Under the hypothesis of a molten earth, steam must have been absorbed either in the original molten state or during the later stages of segregation and ascent, neither of which alternatives seems to be free from difficulties. Under the meteoric hypothesis, it is assumed that hydrogen, carbon dioxide, carbon monoxide, and nitrogen were carried into the whole body of the earth by the infalling matter in some such degree as they are brought to the surface now by meteorites, and that these gases, joined with oxygen derived from the partial reduction of the oxides of the meteoric matter when subjected to the high temperatures of the interior, were extruded by volcanic and similar means and gave rise to the ocean and atmosphere. Under this hypothesis the volcanic gases are regarded as mainly original and as merely lingering expressions

of the process that was much more intense during the later stages of the earth's growth. Cosmic accretions, which may be a notable factor, would be equally functions of either hypothesis so far as the maintenance of the atmosphere and ocean is concerned.

In submitting the newer hypothesis to the test of physical principles and mathematical computations, Fisher has done it an honor that is sincerely appreciated. By showing that its more radical features lie within the tenable limits of theory, he has helped to give it a place as a genuine working hypothesis; and as such it may have some stimulating value as a competitor of the gaseous and molten theory which has practically monopolized geological opinion for the past century.

T. C. C.

Glacial Sculpture of the Bighorn Mountains, Wyoming. By FRANCOIS E. MATTHES. Extract from the Twenty-first Annual Report of the United States Geological Survey, 1899–1900. Washington, 1900.

Glaciation affected the crest of the Bighorn Mountains for more than thirty miles. The range was not covered by a continuous ice cap, and glaciation was confined to valleys. The mountains abound in well developed, elongate, valley-like cirques, which have been but little altered by postglacial changes. The author indorses Johnson's view of the origin of cirques, namely, that they are due to sharply localized and abnormally vigorous weathering, by rapid alternation of freezing and thawing at the exposed bottoms of *bergschrunds*. Mr. Matthes' studies have led him to the conclusion that the location of the *bergschrunds* in any valley is determined by the depth of the névé.

The longest glacier of the Bighorn Mountains is said to have been eighteen miles in length, its terminus reaching down to an altitude of less than 7000 feet. The thickness of the larger glaciers was 1000 to 1500 feet. Small glaciers still exist in the highest part of the range, a little below 44° 30′, at an altitude of about 12,000 feet.

In addition to the account of the effects of the active valley glaciers on topography, the author discusses the effect of inactive snow and névé. The névé effects are described under the term "nivation," and the "nivated" valleys are distinguished from the glaciated valleys. This, so far as we are aware, is the first attempt to analyze the effects of inactive ice and névé on topography. The discussion even involves